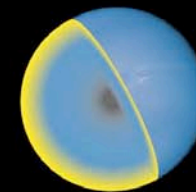
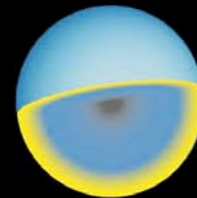
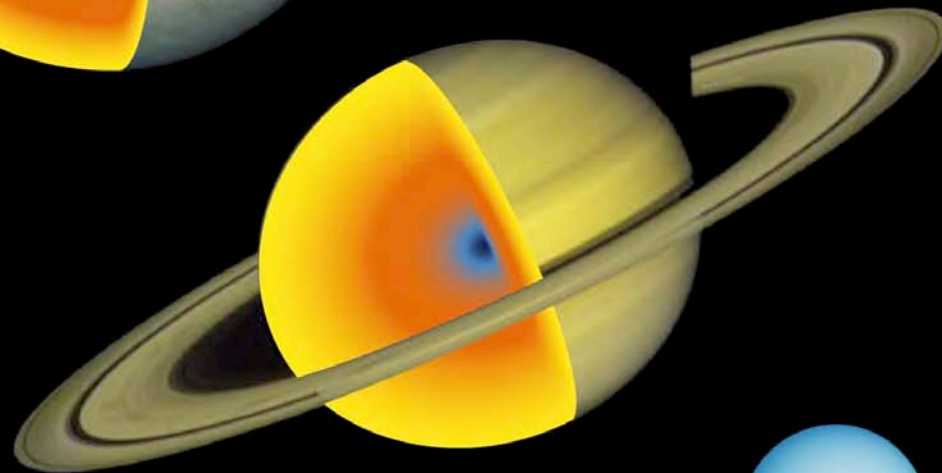
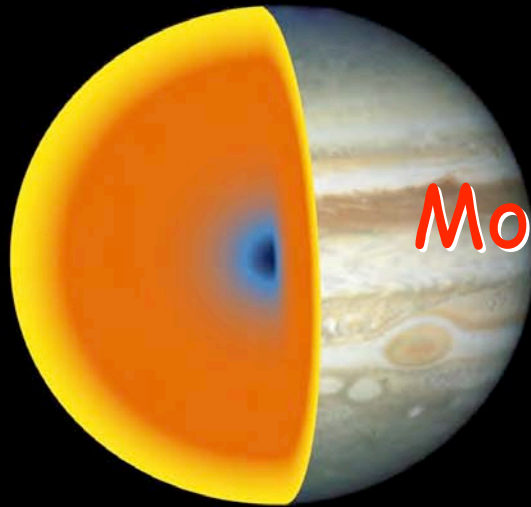


# Giant planets interiors: Models, outstanding questions & probes

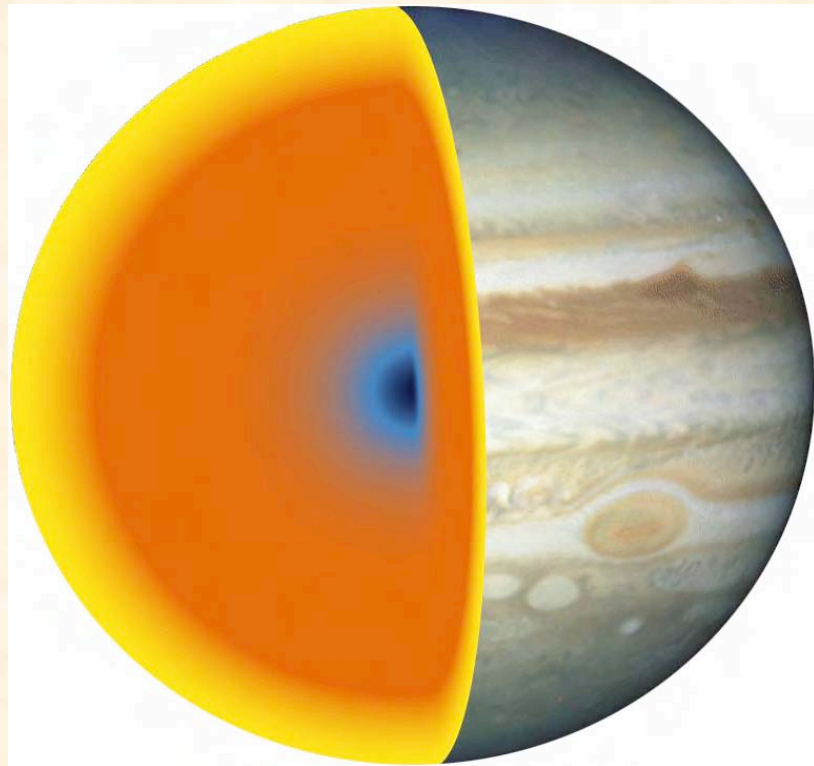


Tristan Guillot

Observatoire de la Côte d'Azur

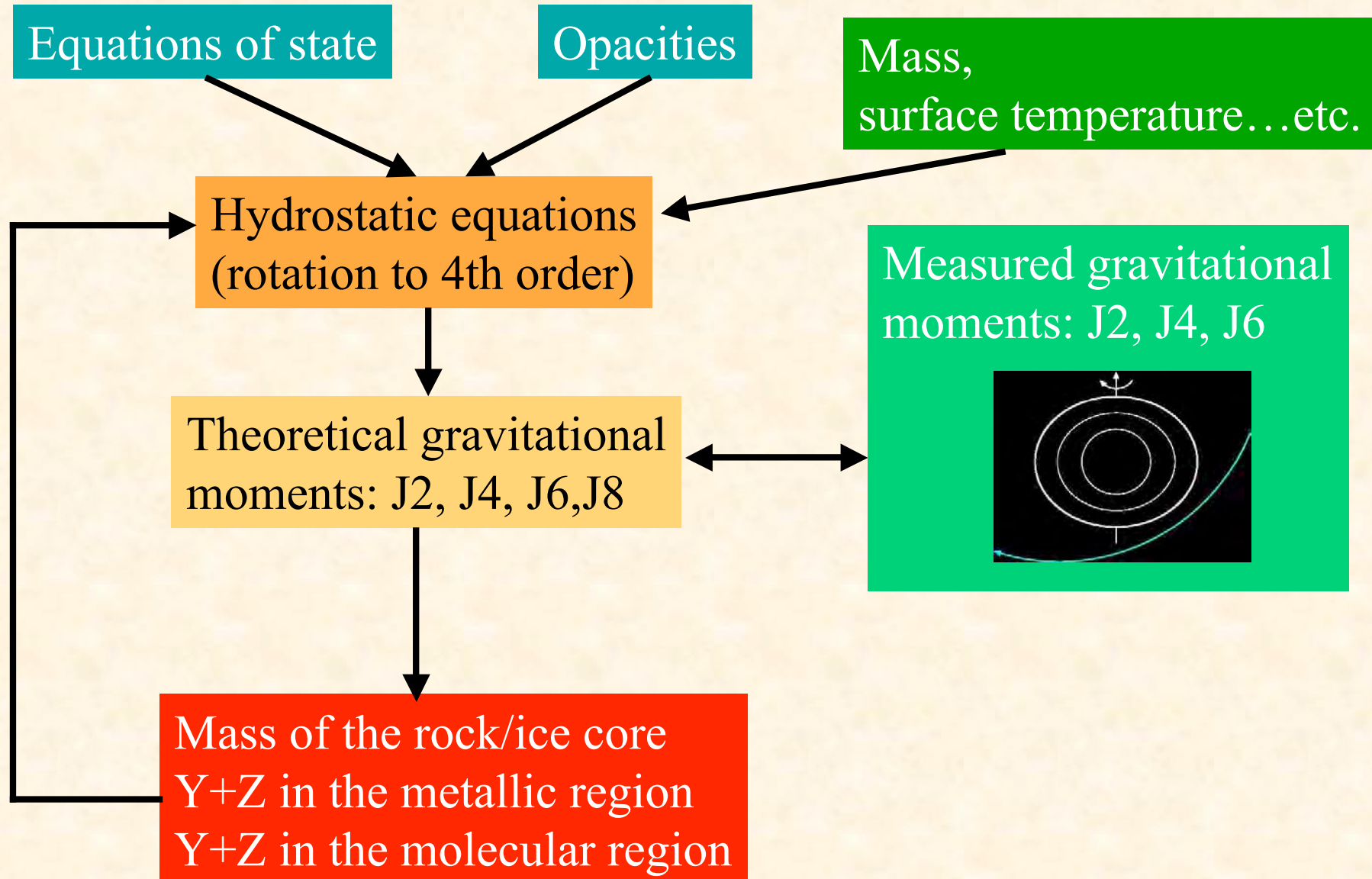
[www.obs-nice.fr/guillot](http://www.obs-nice.fr/guillot)

- Interior structures: principle
  - Jupiter as a benchmark
  - Saturn, Uranus and Neptune
- Enrichments of the atmospheres: possible scenarios
- The role of probes

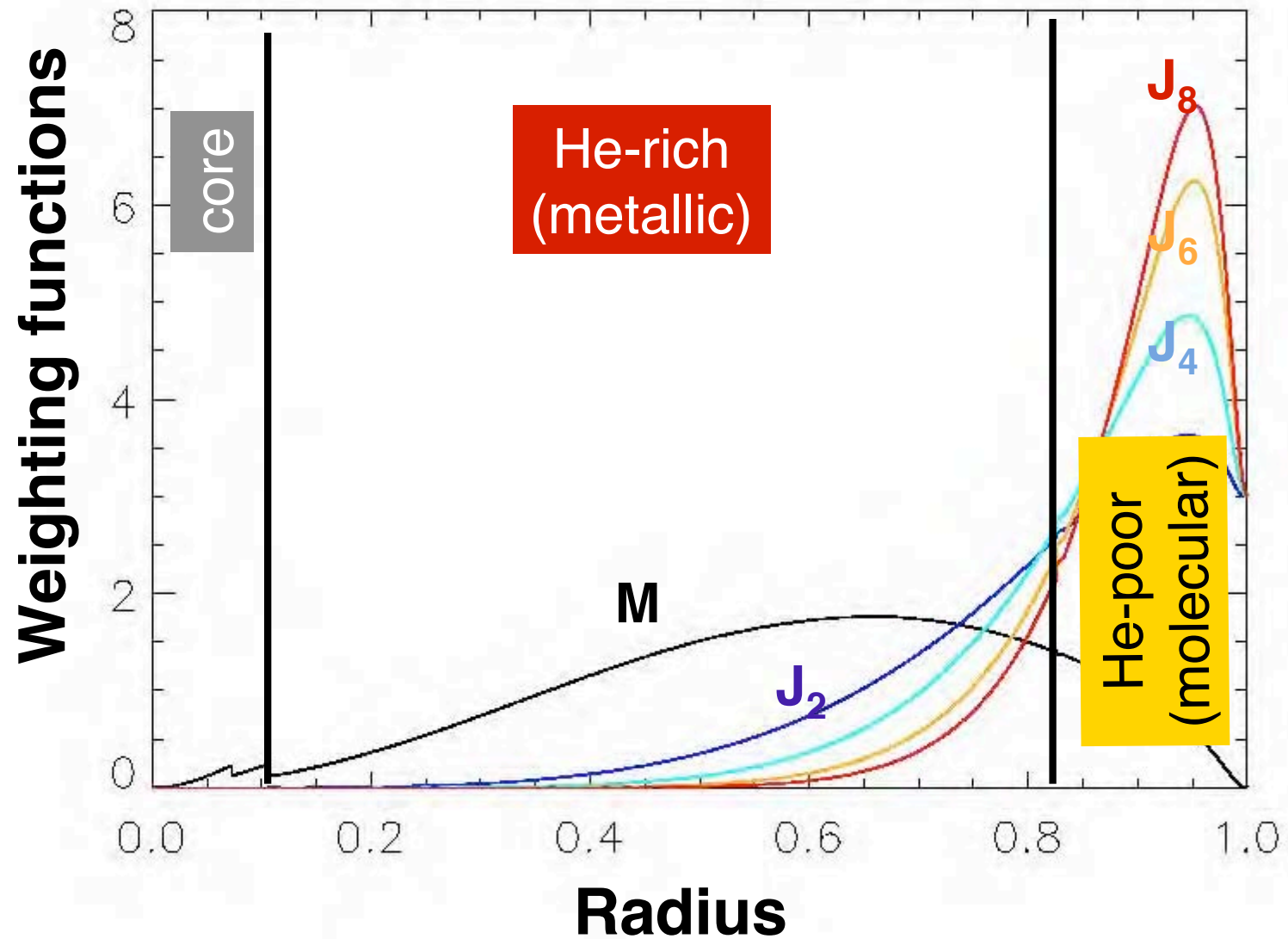


**Jupiter as a benchmark**

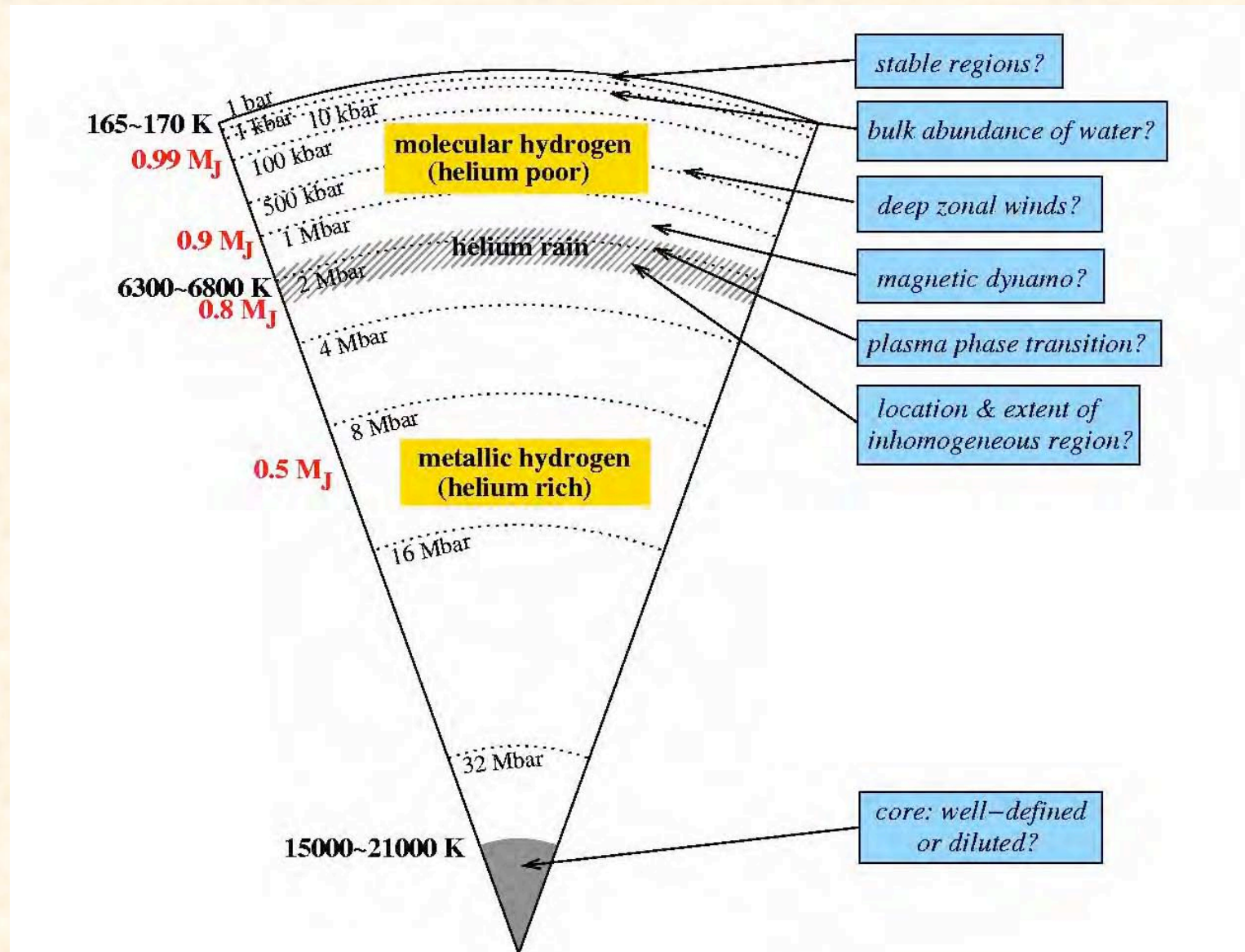
# Interior models: principles



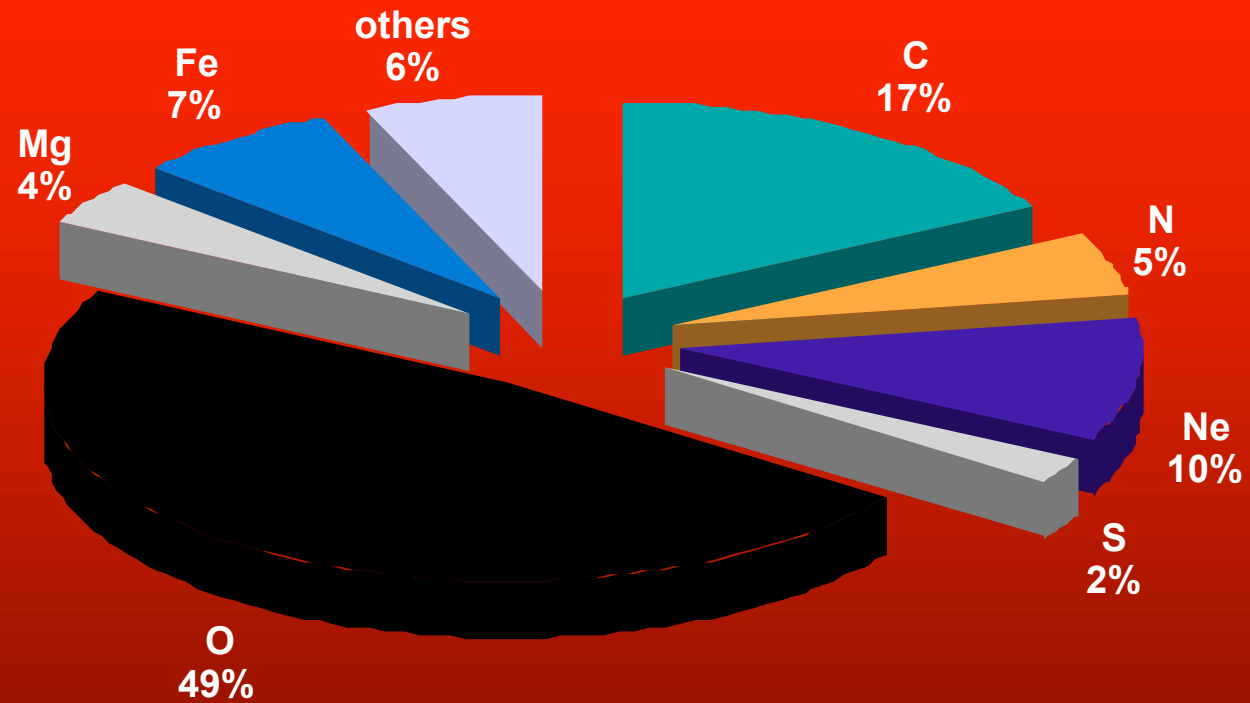
## Constraints from gravity



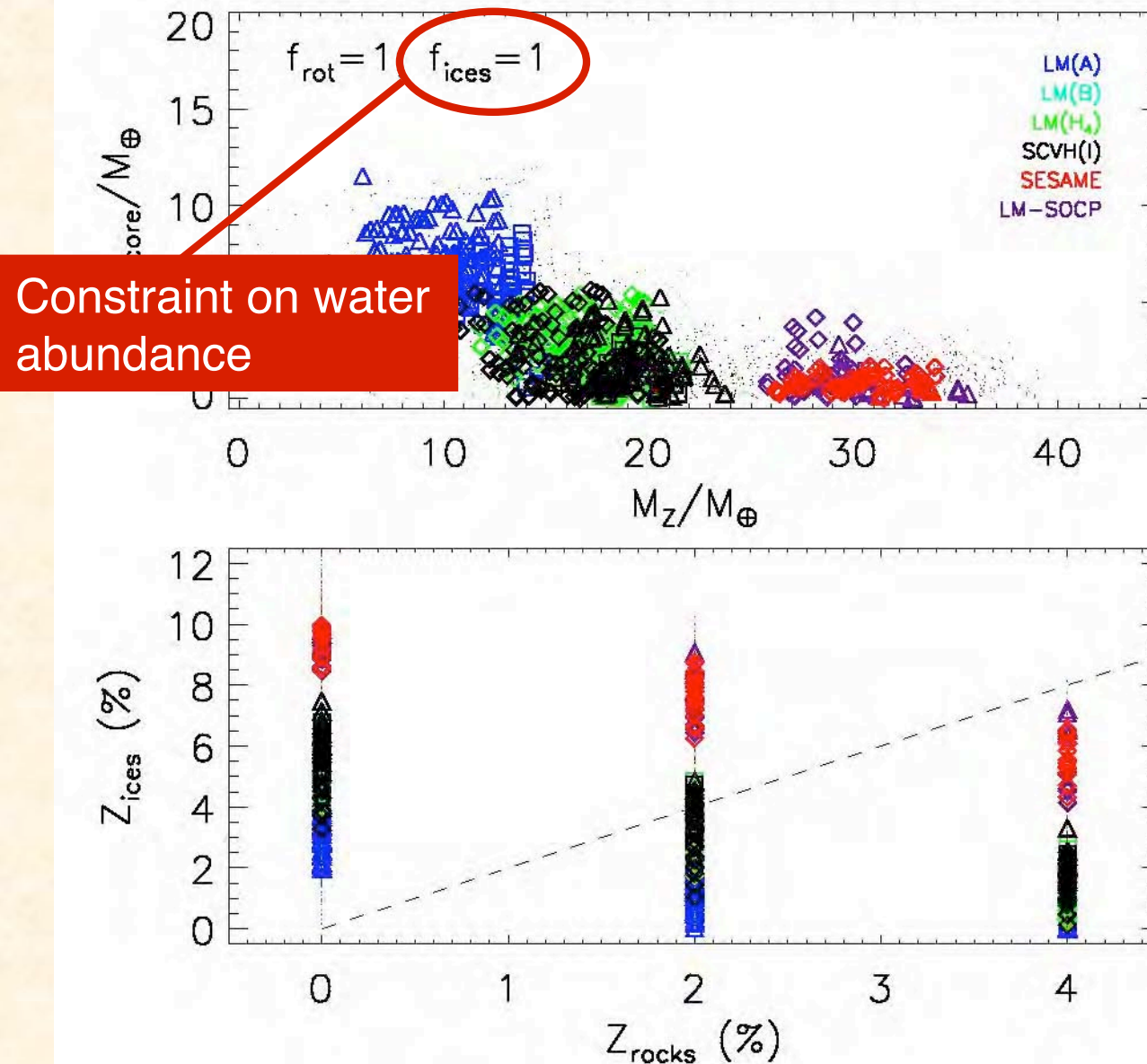
# Outstanding questions



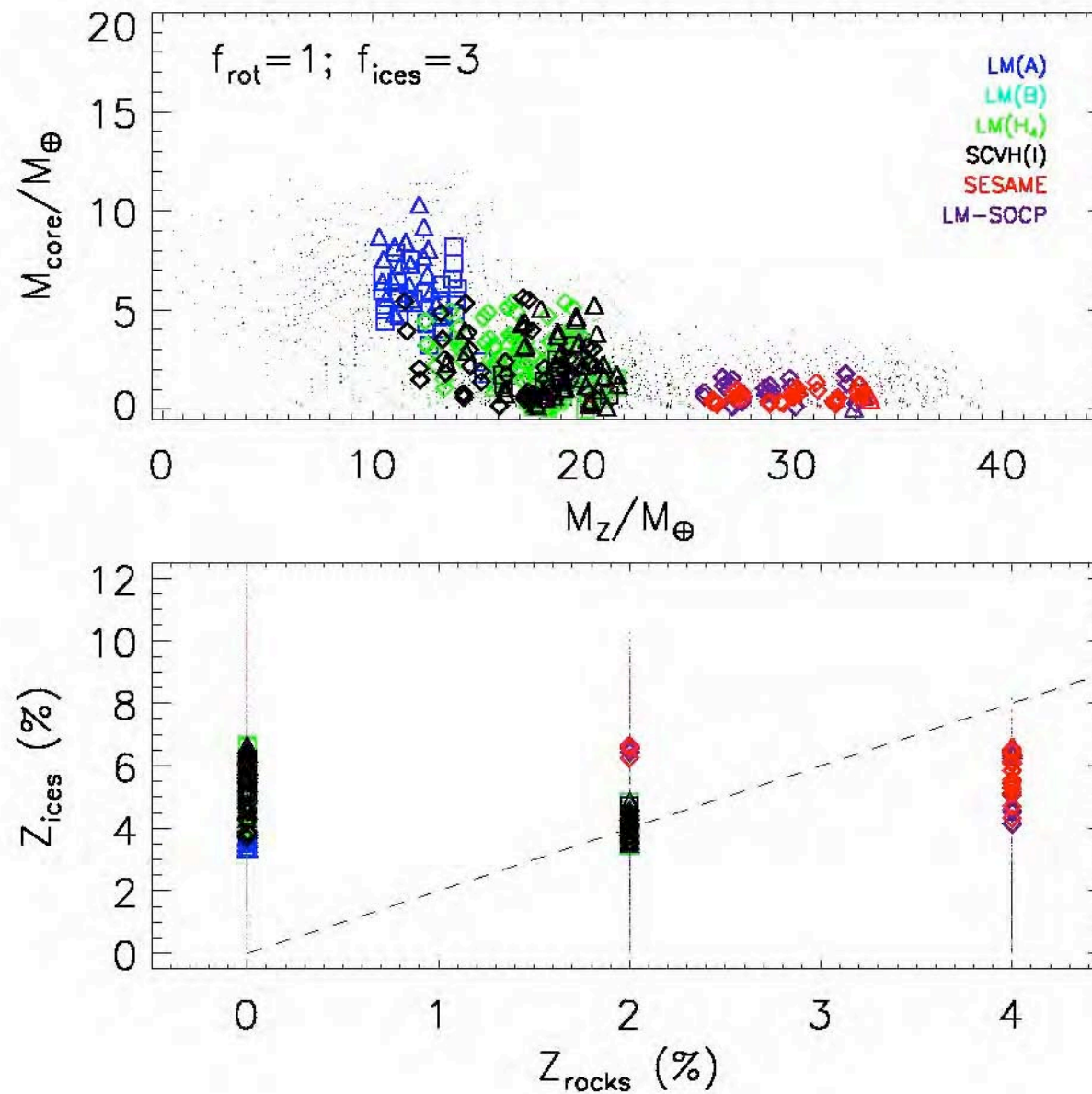
# The importance of water



# Constraints on Jupiter 's interior

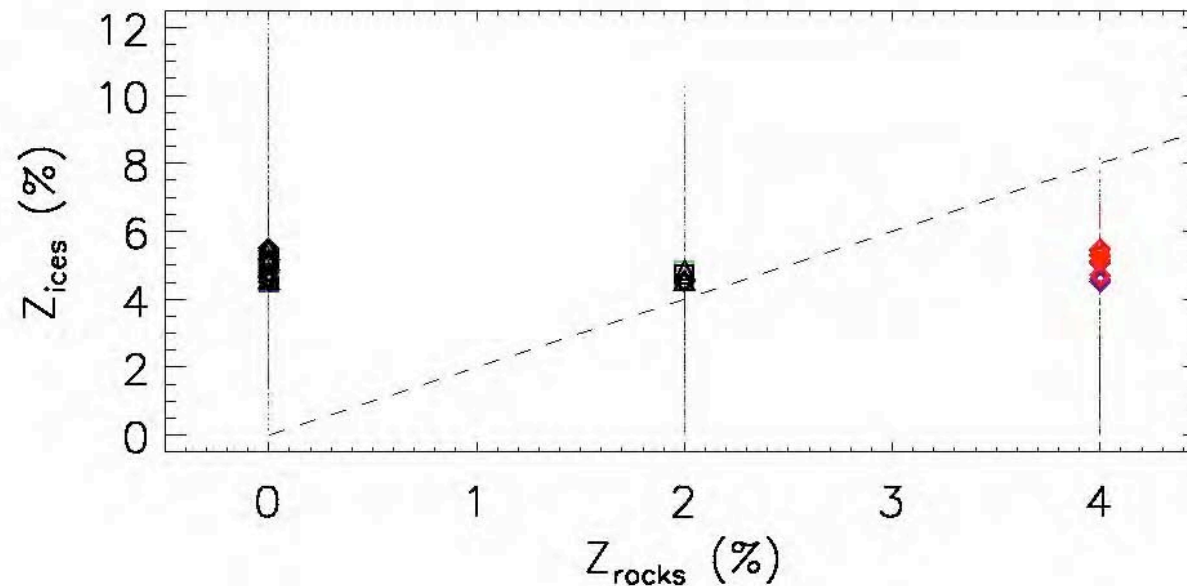
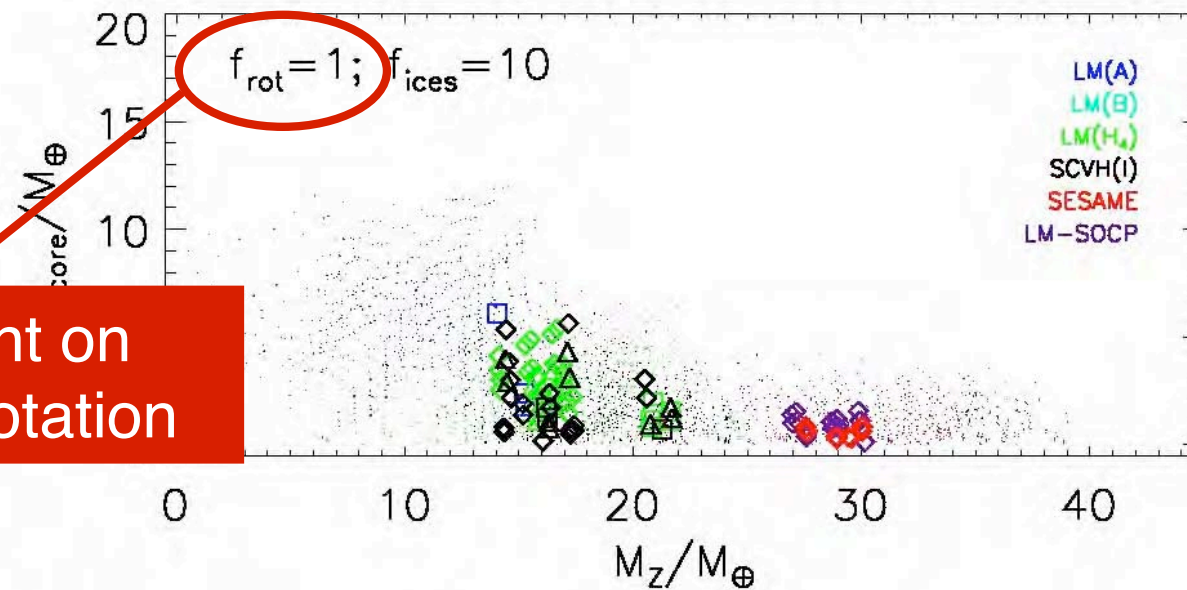


# Constraints on Jupiter 's interior

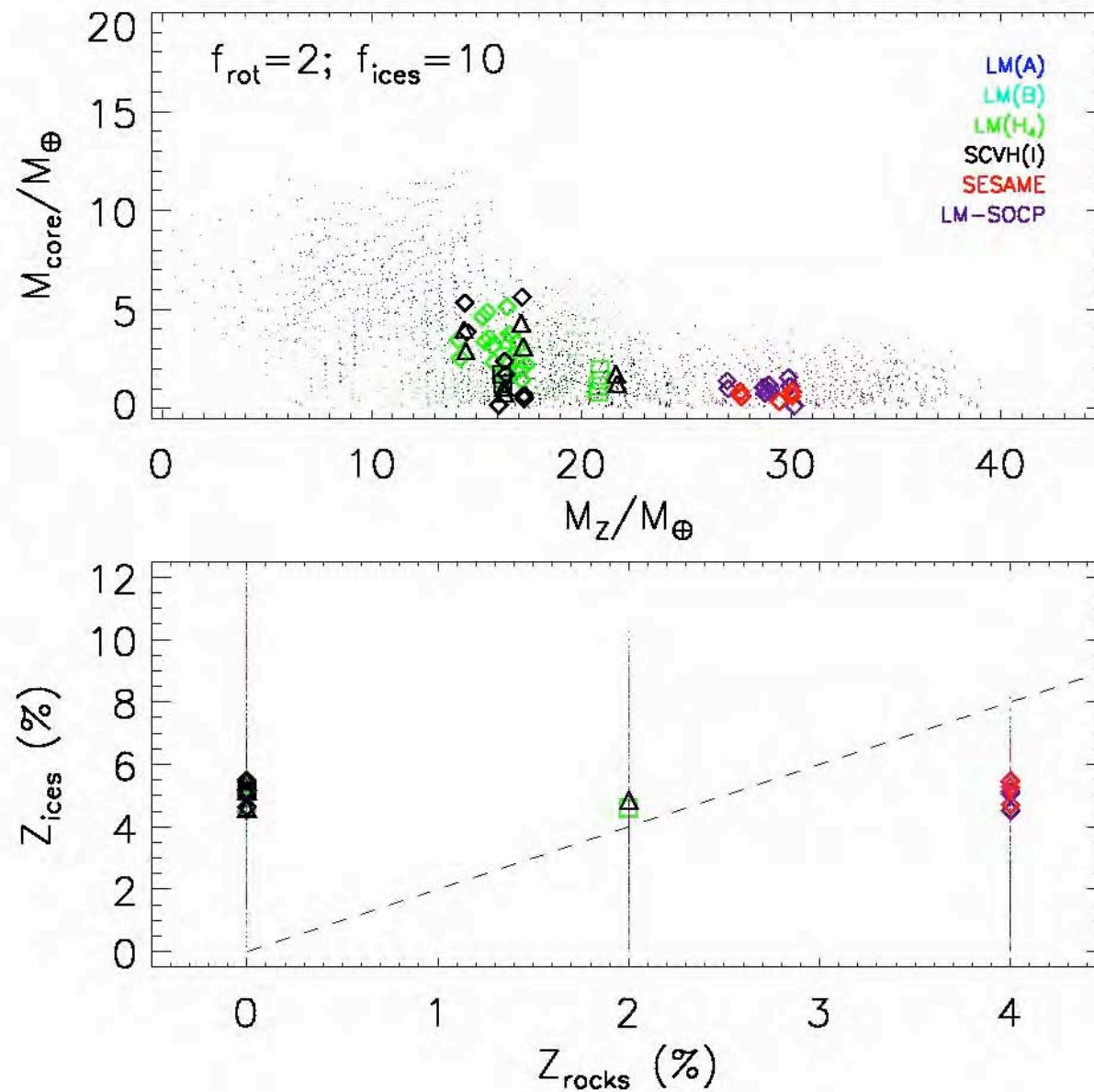


# Constraints on Jupiter 's interior

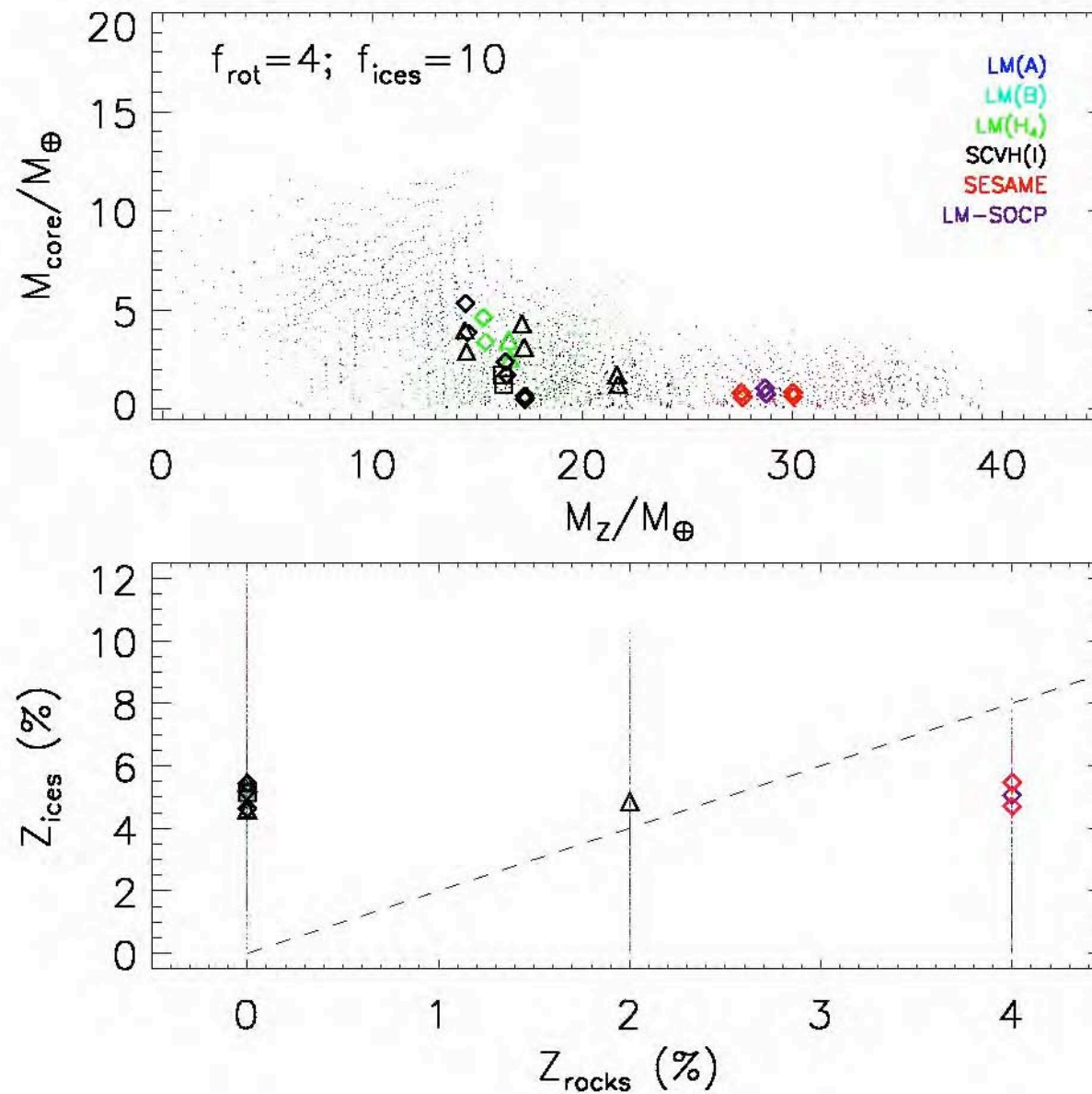
Constraint on  
interior rotation



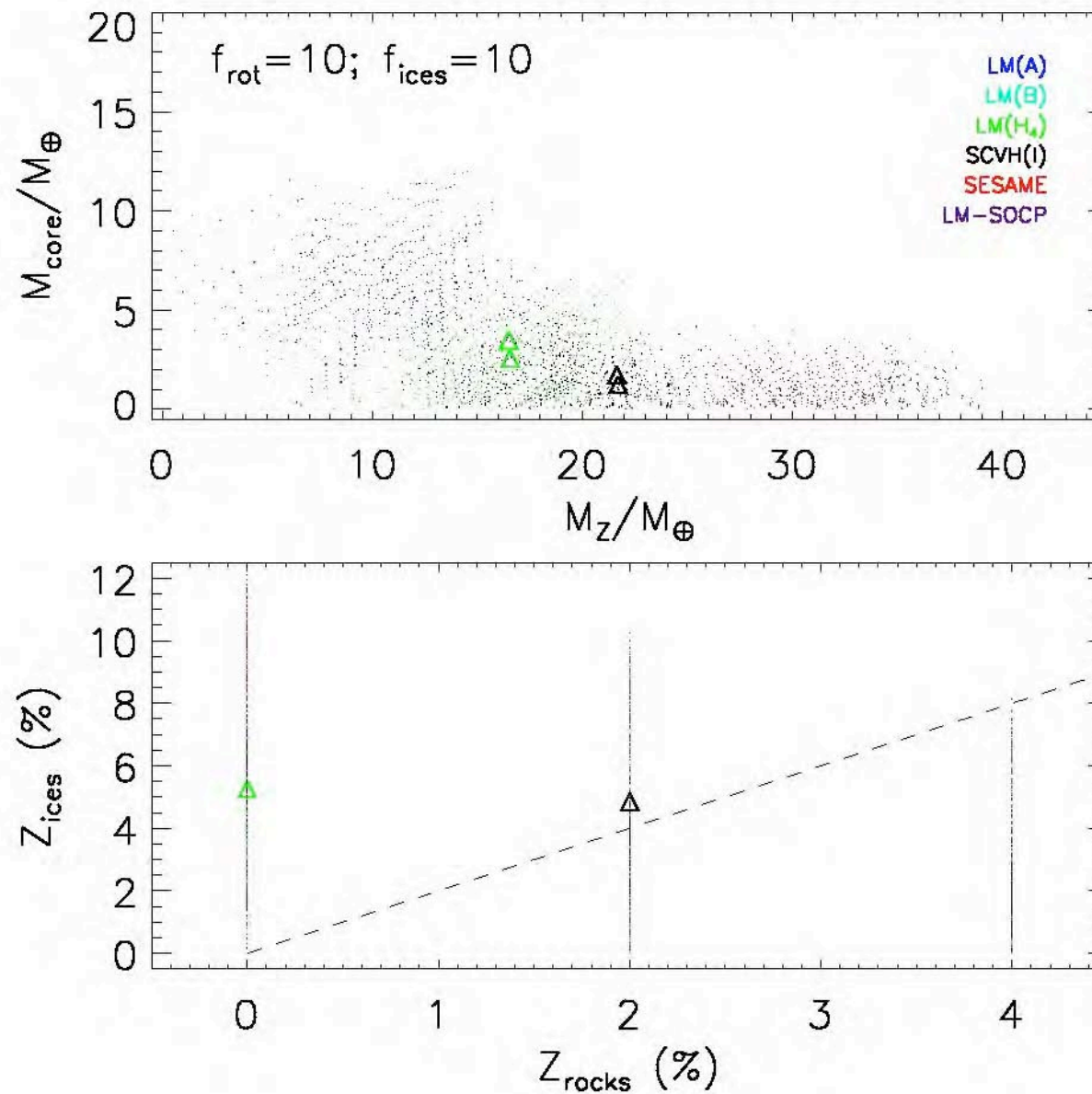
# Constraints on Jupiter 's interior

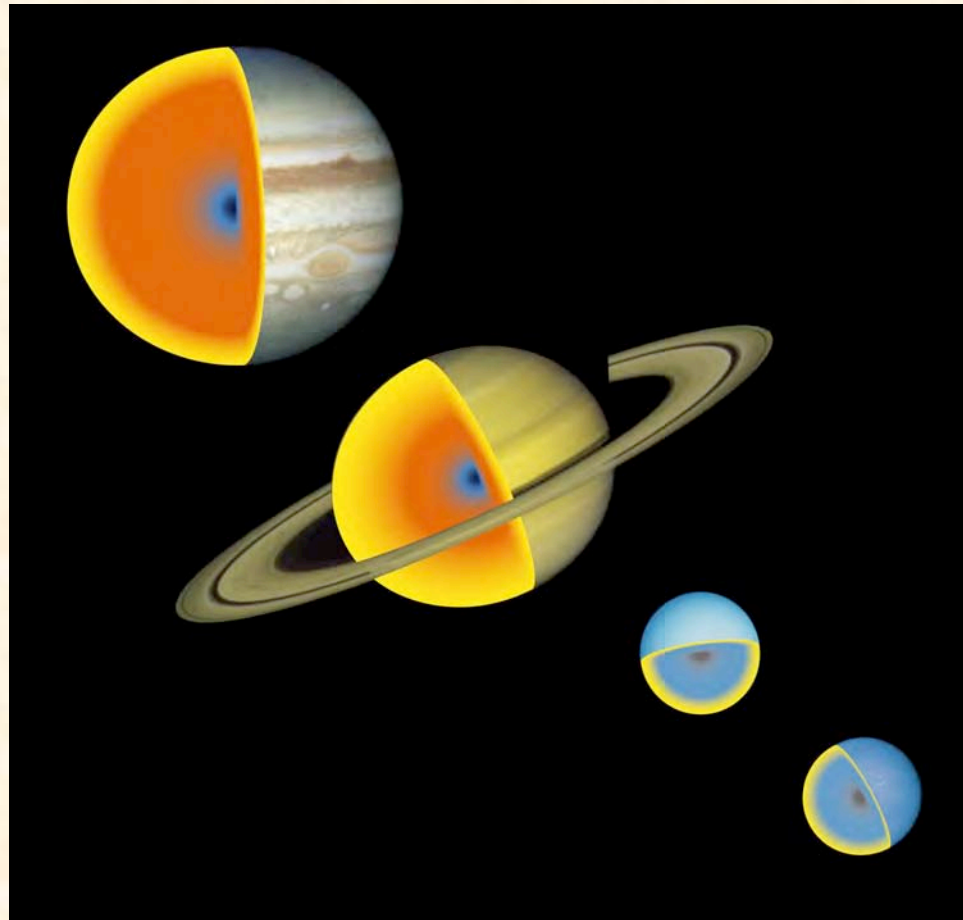


# Constraints on Jupiter 's interior



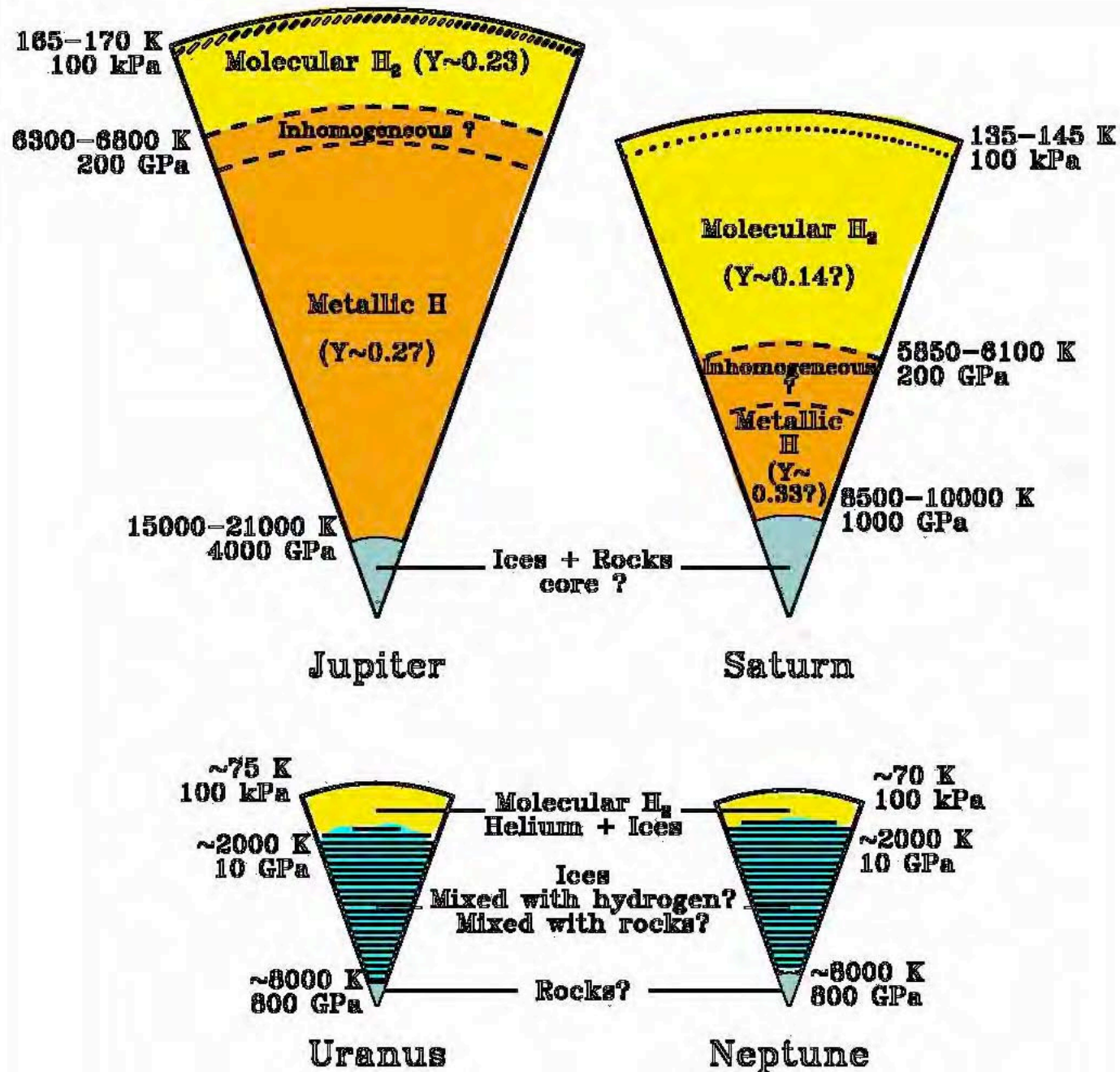
# Constraints on Jupiter 's interior





**Saturn  
Uranus  
& Neptune**

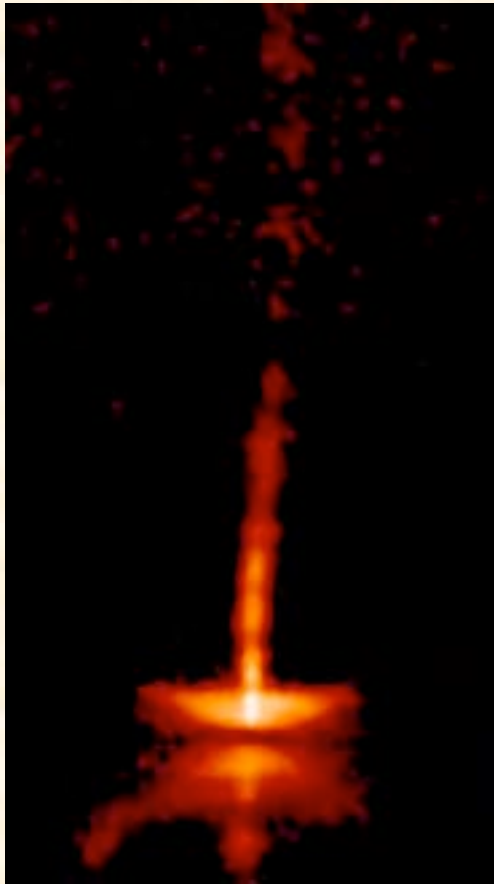
# Internal structures



## Link atmosphere-interior-core mass

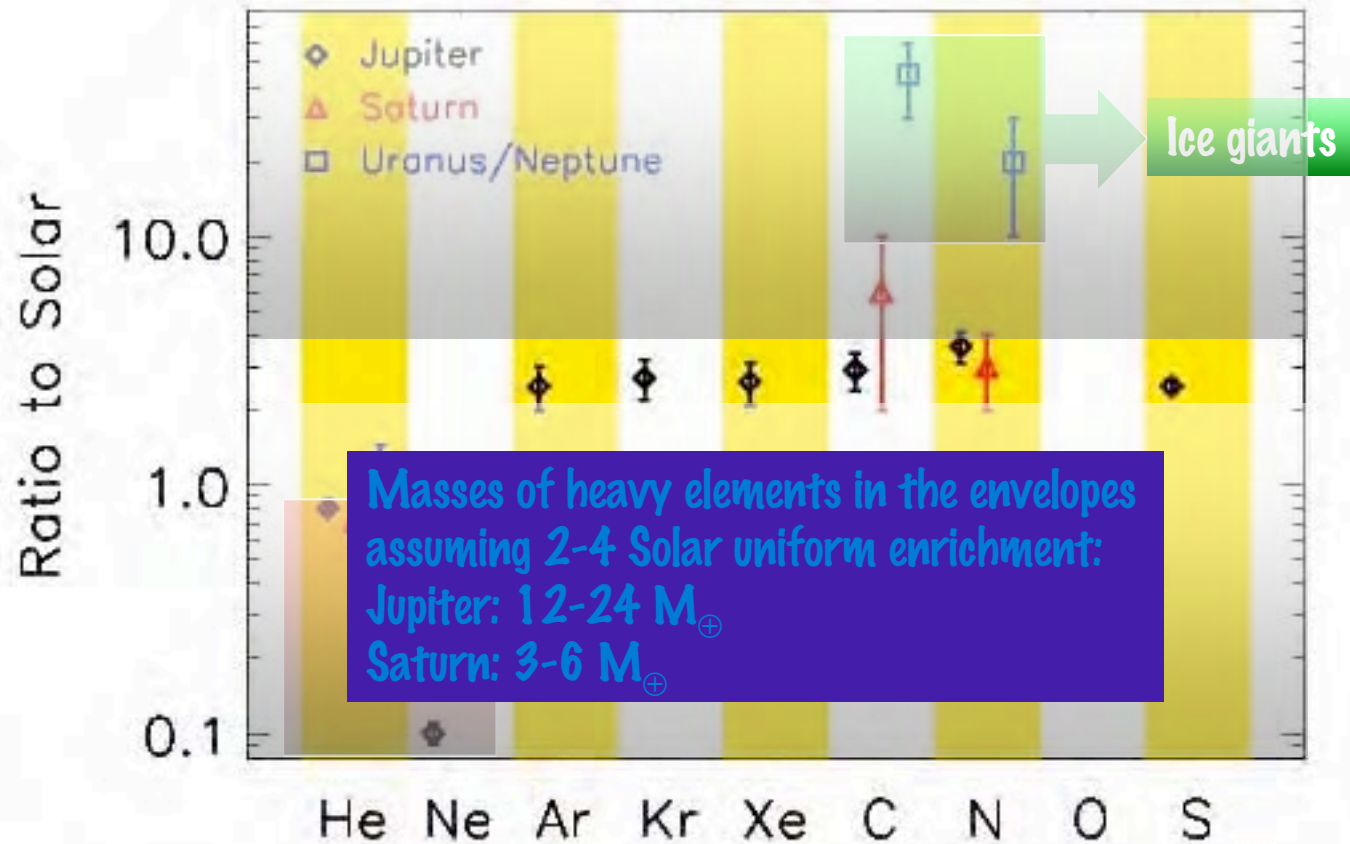
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- Less clear for Saturn than Jupiter due to a relatively smaller envelope
- Absent for Uranus and Neptune:
  - no direct link between the composition of the atmosphere and that of the rock/ice core.
  - Mass of H-He atmosphere is only 1-4  $M_{\oplus}$



**Atmospheric abundances:  
what do they tell us?**

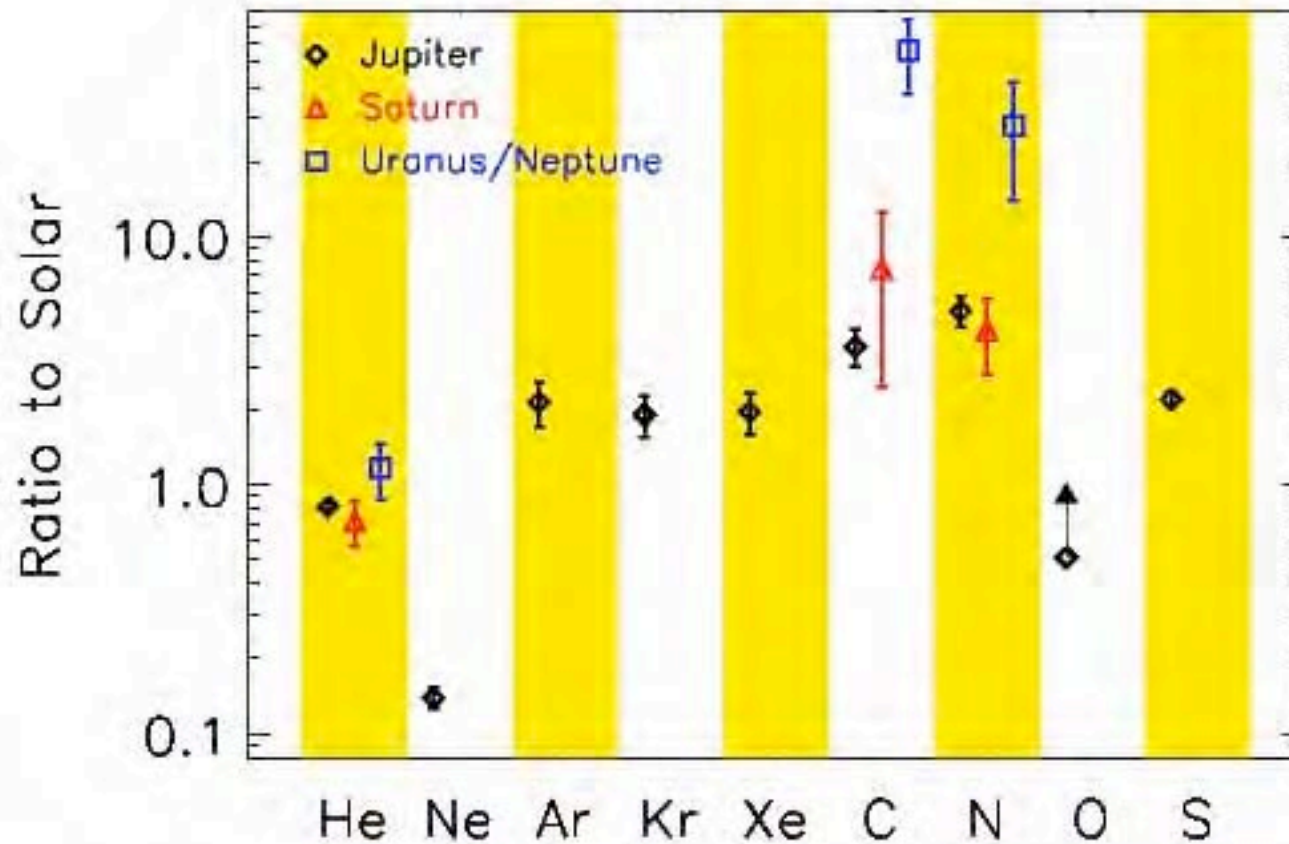
# Tropospheric compositions



See Atreya et al 2003, Gautier et al 1995.

Solar reference: Anders & Grevesse 1989

# Tropospheric compositions



See Atreya et al 2003, Gautier et al 1995.

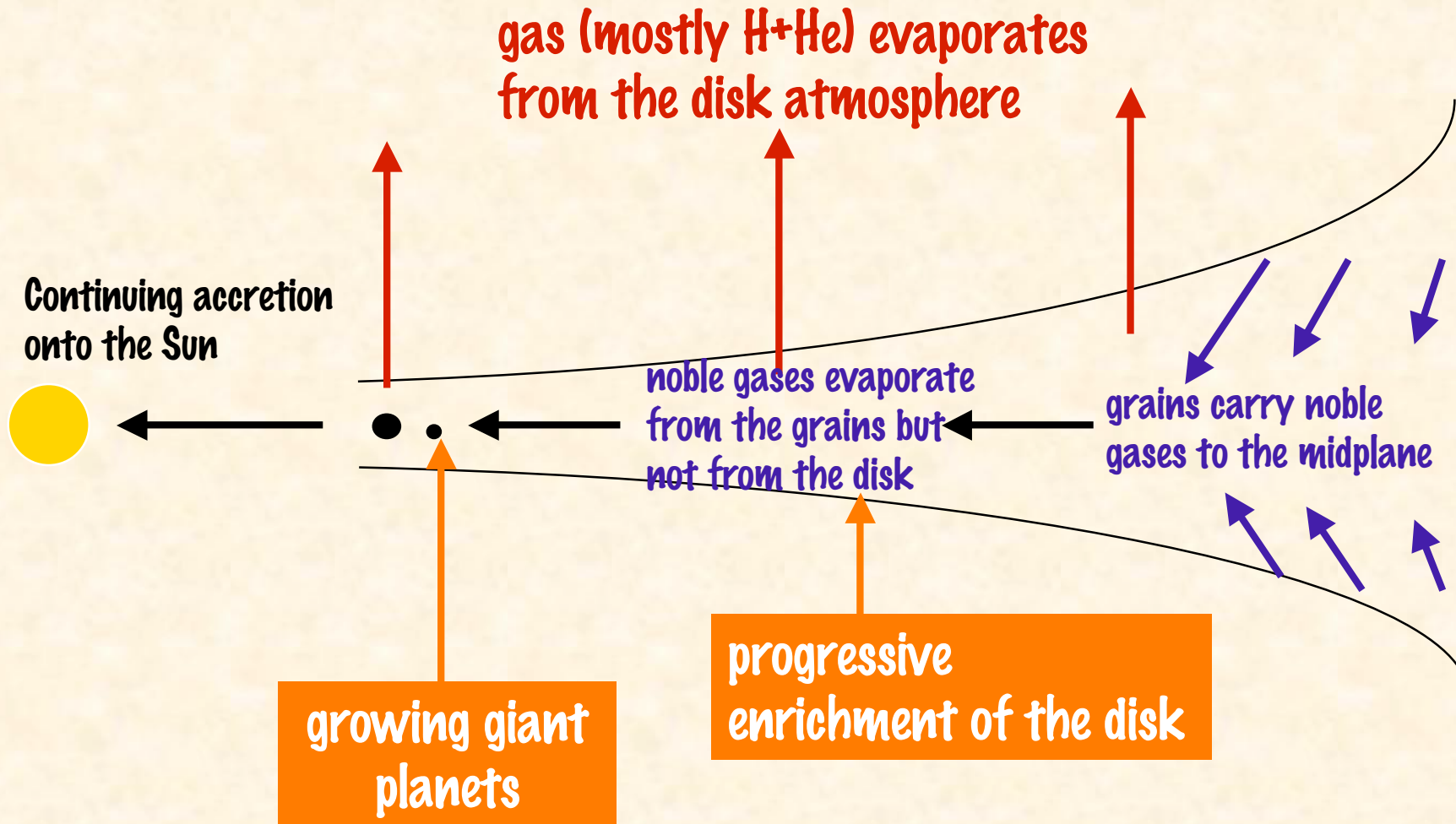
Solar reference: Grevesse & Sauval 2002

# The enrichment of the atmospheres

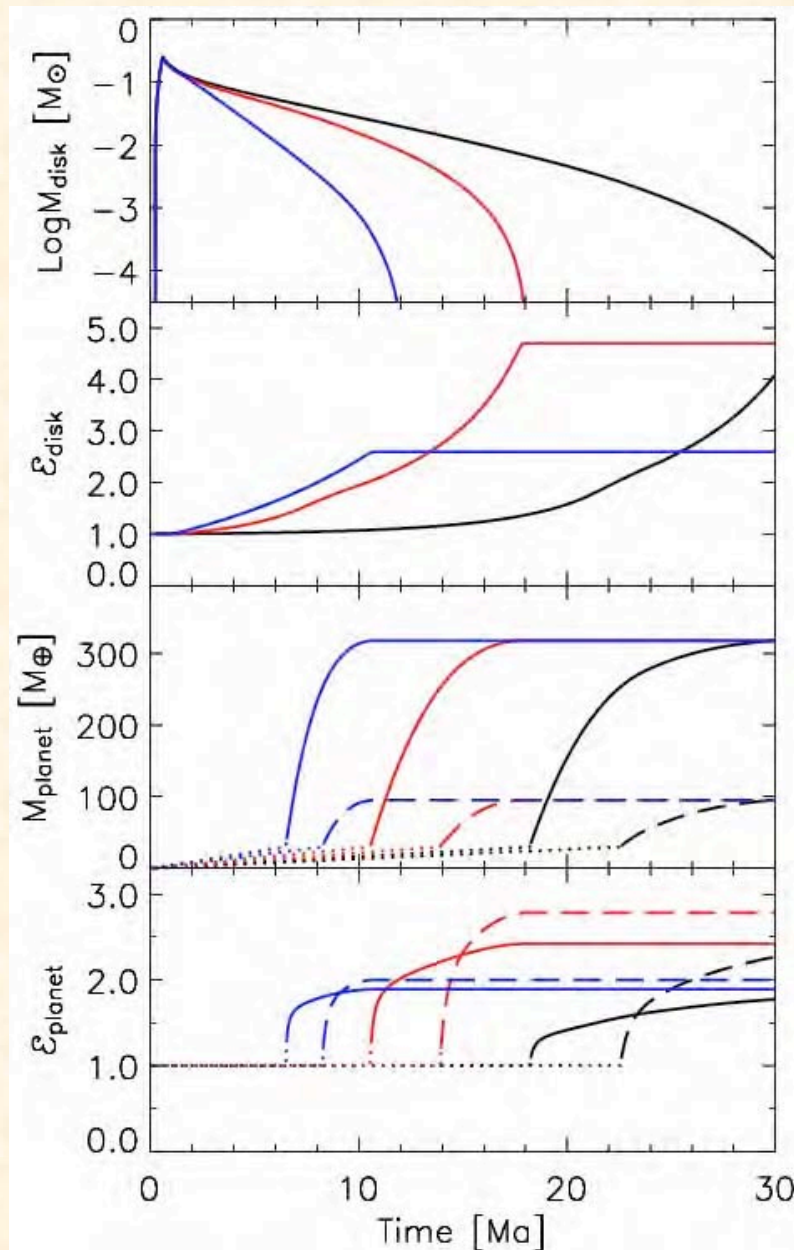
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- 3 possible causes:
  - Efficient delivery of solid planetesimals
    - This most certainly has to occur early during the formation process
  - Core erosion
    - Would explain why Jupiter appears to have a smaller core than Saturn
  - Formation of giant planets in an enriched protosolar disk
- The noble gases are keys to distinguish between the different scenarios
  - But we need their abundances in at least 2 planets...

# The "Nice" model of giant planet formation



# The "Nice" model of giant planet formation



Disk mass

Disk enrichment

Planet mass

Planet enrichment  
Jupiter: plain  
Saturn: dashed

---

**Perspectives...**

# Probe measurements and scientific rationale

	Jupiter	Saturn	Uranus	Neptune
He	✓	H-He phase diagram; J/S evolution	He fractionation in the protosolar disk (thermal evaporation)?	
Major species except H <sub>2</sub> O	✓	✓	Atmospheric enrichment; Meteorology; Planetesimal delivery	
H <sub>2</sub> O	Solar system water inventory; Planet formation; Meteorology		Dynamics of the deep atmosphere	
Noble gases	✓	Test formation scenarios; Envelope enrichment by planetesimal delivery or gas accretion of a chemically evolved protosolar disk		
Disequilibrium species (eg CO, PH <sub>3</sub> , GeH <sub>4</sub> ...)	(✓)	(✓)	Constraints on mixing in the deep atmosphere and compositions	
Isotopic ratios: D/H <sup>16</sup> O/ <sup>17</sup> O/ <sup>18</sup> O <sup>14</sup> N/ <sup>15</sup> N, <sup>12</sup> C/ <sup>13</sup> C...	Timing of planet formation; Location of planet material in the protosolar disk			
Extinct radionuclides with gas-loving daughter species: e.g. <sup>41</sup> Ca→ <sup>41</sup> K; <sup>129</sup> I → <sup>129</sup> Xe	Ice/Rock ratio; Timing of planet formation			

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Shallow probe



Multiple probes



Deep probe



Extremely deep probe

# All giant planets should eventually be probed!

- Our four giant planets each have unique features
- Planet formation was a very stochastic process (e.g. work from Morbidelli et al. 2005)
  - The early Solar System may have had Jupiter, Saturn, Neptune, and Uranus as the furthest planet!

